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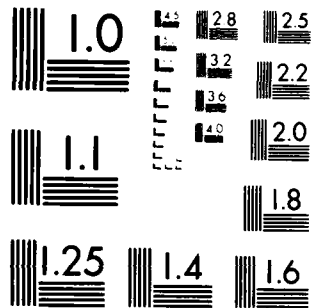
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ATMOSPHERIC PROPAGATION EFFECTS ON INFRARED RADARS

Final Report

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Massachusetts Institute of Technology

U.S. Army Research Office Contract DAAG29-80-K-0022

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## ATMOSPHERIC PROPAGATION EFFECTS ON INFRARED RADARS

### Abstract

Compact coherent CO<sub>2</sub> laser radars have the potential for greatly improved angle, range, and velocity resolution relative to their micro-wave radar counterparts. This research program was aimed at obtaining quantitative understanding of target reflection and atmospheric propagation effects on such laser radars through a combination of theory and experiments. Toward those ends, improved statistical signal models were developed, and corroborated through measurements, for turbulence and speckle effects in 2-D pulsed imager operation. Speckle and clutter effects in 2-D Doppler imager operation were also studied through analysis and measurements. Possible bad-weather laser radar operation, using scattered light, was considered theoretically, but shown to require use of a different laser wavelength than the 10.6  $\mu\text{m}$  CO<sub>2</sub> laser wavelength. A theoretical study of the use of high time-bandwidth (TW) product signal waveforms in 3-D imaging radars was also performed. The experimental portions of the research were carried out under a collaboration arrangement with the Opto-Radar Systems Group at MIT Lincoln Laboratory.



## I. Research Summary

The development of laser technology offers new alternatives for the problems of target detection and imaging. In particular, compact coherent CO<sub>2</sub> laser radars have the potential for greatly improved angle, range, and velocity resolution relative to their microwave radar counterparts. The performance of laser systems, however, may be severely limited by target-return fluctuations originating from target reflection characteristics (notably laser speckle) and atmospheric turbulence. This document constitutes the final report on a program aimed at developing a quantitative understanding of the impact of speckle and turbulence on coherent laser radar systems through a combination of theoretical and experimental work. Under a collaboration arrangement with the Opto-Radar Systems Group of the MIT Lincoln Laboratory, the experimental portions of the research were carried out on the compact CO<sub>2</sub> laser radars under development there [1], [2]. In what follows, we shall summarize the principal results that were obtained in the various problem areas that were studied.

2-D Pulsed Imager: In a precursor to this program, which was funded through the MIT Lincoln Laboratory [3], [4] and later published in [5], we developed statistical models for the combined effects of target speckle and glint plus atmospheric turbulence on the performance of a 2-D pulsed imager coherent laser radar. Under the program being reported here, experiments to corroborate the preceding analysis were performed, and improvements and extensions of the models were developed [6]-[11]. The key findings were as follows: turbulence-induced beam jitter must be included in realistic radar modeling; jitter-corrected retro-reflector returns do show turbulence-induced lognormal scintillation; and turbulence-induced beam jitter is the cause for staring-mode

speckle target decorrelation. We also showed that any contemplated use of scattered light to achieve useful radar operation deep into bad weather conditions will have to choose a wavelength with much higher albedo than that of the  $10.6\text{ }\mu\text{m CO}_2$  laser wavelength.

2-D Doppler Imager: In order to understand the potential utility of a 2-D Doppler imager as a moving target indicator (MTI) radar [12], we extended our analysis and measurements work to include the speckle and clutter statistics of such systems [13], [14]. Here we found the far-field observations of moving, rough-surfaced hard targets did show the expected speckle behavior, but, unaccountably, speckle noise was greatly reduced in near field observations. We also succeeded in decomposing the spectrum of clutter returns from wind-blown trees into a micro-motion contribution plus a macro-motion contribution. From this decomposition, the clutter-limited false alarm probability can be calculated as a function of the minimum velocity being sought in the radar, subject to some remaining uncertainties in the amplitude statistics of the clutter signature.

3-D Imager: The use of high time-bandwidth (TW) product signal waveforms may offer some advantages in laser radars which seek to do 3-D imaging. In a theoretical study [15], we addressed the relative merits of three principal high TW waveform classes: sinusoidal amplitude-modulated (am-cw) waves, sinusoidal frequency-modulated (fm-cw) waves, and linearly frequency-modulated (chirped) waves. This work concentrated on the effects of range-spread speckle targets and assumed the simple signal processors that have been suggested for practical use of the preceding waveforms. We found that chirped signals have a definite advantage over the sinusoidal waveforms in that they can be used against multiple targets in a given azimuth/elevation bin without seriously degraded range accuracy.



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- [15] A.H. Tewfik, "Range-Spread Speckle Target Effects on CW Coherent Laser Radar Range Measurements," S.M. Thesis, Dept. of Elect. Eng. and Comput. Sci., MIT, March 1984.

### III. Personnel

The research reported here was carried out by

Prof. Jeffrey H. Shapiro, principal investigator

Dr. Robert C. Harney, senior investigator (6/15/80 - 4/30/82)

Dr. Robert J. Hull, senior investigator (5/1/82 - 3/31/84)

Dr. David M. Papurt, research assistant (Ph.D. 1982)

Mr. Sun T. Lau, research assistant (S.M. 1982)

Ms. Paula L. Mesite, research assistant (S.M. 1983)

Mr. Ahmed H. Tewfik, graduate student (S.M. 1984)

Mr. Martin B. Mark, graduate student

Mr. Hai V. Tran, research assistant

Mr. Rodney R. Robertson, undergraduate student (S.B. 1982)

#### IV. Publications

The following journal articles, meeting papers, and theses have been produced under U.S. Army Research Office Contract DAAG29-80-K-0022.

1. J.H. Shapiro, "Linear vs. Logarithmic Frame-Integration for Coherent Laser Radars," presented at the 1981 IEEE International Sympos. on Inform. Theory, Santa Monica, CA, Feb. 1981.
2. D.M. Papurt, J.H. Shapiro, and R.C. Harney, "Atmospheric Propagation Effects on Coherent Laser Radars," Proc. SPIE 300, 86-99 (1981).
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10. J.H. Shapiro and P.L. Mesite, "Performance Analyses for Doppler and Chirped Laser Radars," IRIS Active Systems Specialty Group, 1983.
11. A.H. Tewfik, "Range-Spread Speckle Target Effects on CW Coherent Laser Radar Range Measurements," S.M. Thesis, Dept. of Elect. Eng. and Comput. Sci., MIT, March 1984.

